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Land Surface Temperature Measurements from EOS MODIS Data

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1. Task Objectives

1) To complete a design/performance analysis of thermal infrared spectrometers, to submit a purchase request, and to make a purchasing order of a spectrometer which meets basic requirements for land-surface emissivity and temperature measurements in the field.

2) To develop experimental and data processing procedures for land surface emissivity and temperature measurements in the field.

3) To develop calibration and validation plans for the land-surface temperature algorithm.

2. Work Accomplished

2.1. Design/Performance Analysis of Thermal Infrared Spectrometers

I have contacted more than ten companies in the last two years in order to find a spectroradiometer suitable for my applications. There are three types of optic design (interferometry, grating and CVF, i.e., circular variable filter) for thermal infrared spectrometers. Several spectrometers with a list of brief technical information and specifications are list in Appendix 1. I have received free demonstrations from CI Systems Inc. and MIDAC Corp., but I could not have a demonstration from BOMEM unless I travel to BOMEM in CANADA. After analyzing general information of each spectrometer and signal-to-noise ratios (SNR) of demonstration data, I decided to select the MIDAC M2401 spectrometer, which is a thermal infrared interferometer, although other systems such as BM155, Optronic 750D and CI SR-5000 may work in wider spectral ranges and have more options. The main reasons to select MIDAC M2401 with an InSb/MCT detector are 1) it is relatively less expensive; 2) it is more portable (only 27 lbs, it is less than half weight of others); 3) it has a high spectral resolution in the 2.5-16 µm range; 4) it has a good performance (SNR >25 at 3.75 µm, SNR >500 at 8.55 and 11 µm, according to the statistics of 16 spectra collected by a LN2 cooled MCT detector. An InSb/MCT sandwich detector is expected to improve the SNR at 3.75 µm by a factor of about four); 5) According to the demonstration data from MIDAC M2401 with the blackbody we used at JPL, it appears that the linearity of response functions is quite good at wavelengths 8.55 and 11.03µm, as shown in Figure 1. But M2401 data show a significant nonlinearity in the medium wavelength range, as shown in Figure 2 for wavelength 3.75 pm. Where measurement data are shown by symbol x. Because of its significant nonlinearity, a quadratic regression relation has to be used to calibrate the response function. The points indicated by symbol ❑ show the calculated radiance values at lower temperatures with the quadratic regression relation. The symbol A indicates the effect of the blackbody surface emissivity less than 1. It is expected that the InSb/MCT sandwich detector will improve the linearity in the medium wavelength range.

A blackbody with an aperture of at least 7“ by 7“ is required to make calibration of thermal infrared spectrometer in the laboratory and in the field. After making comparisons of performance, weight, and price between blackbodies from several different companies, I selected one blackbody from CI Systems Inc. It is priced at $9.9K and has a clear aperture 7“ by 7“ for temperature range 5-75°C in a resolution 0.01 ‘C, and weight of 26 lbs (additional 33 lbs for controller). It is worthy to note that the specification of the surface emissivity of blackbodies with a large size aperture is quoted as 0.97 or 0.98 ±0.02 by most companies. There is no any ideal blackbody commercial y available in the affordable price range. The reason for a blackbody is the need for its temperature controller and stability rather than its so called “black’ surface.

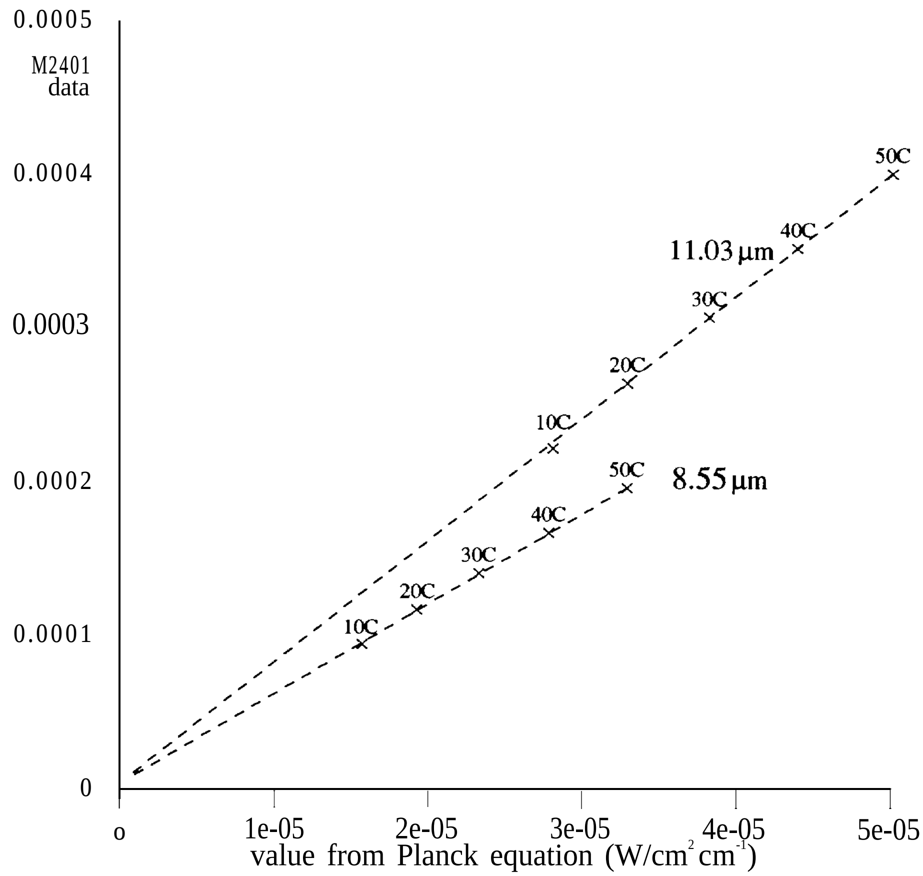

Figure 1. The relation between M2401 data and values calculated by Planck equation at 8.55 and 11.03 µm.

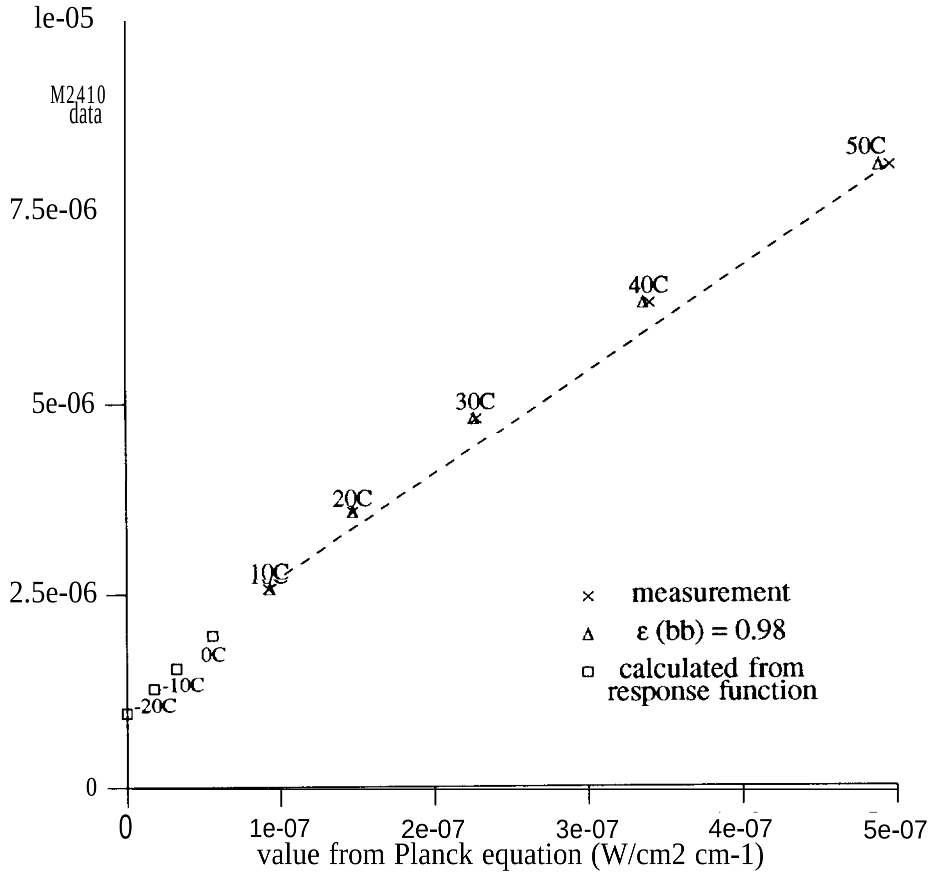

Figure 2. The relation between M2401 data and values calculated by Planck equation at 3.75µm.

2.2. Development of Procedures for Land-surface Emissivity and Temperature Measurements

Practical and accurate procedures for land-surface emissivity and temperature measurements in the field are being developed. In the conventional "black box" method for surface emissivity measurements, the temperature of a target surface is assumed not to change when the thermal radiation source is turned on or off. Thus measured emissivity sometimes is larger than one. I will use the direct solar beam as the thermal radiation source in the medium wavelength range and measure the downward atmospheric radiation. Separate measurements will be taken when the target surface is exposed to the solar beam and is blocked from the solar beam. The temperature change of the target surface will be estimated by using the radiance difference in the wavelength range 10-12 µm based on an initial "guess" value of the target surface emissivity. After correction of the temperature change, the radiance difference in the medium wavelength range will be used to estimate surface reflectivity y and temperature. And then the "guess" value of emissivity at long wavelengths will be updated based on the estimated temperature value. Numerical simulations show that an iterative method could improve the accuracy. Numerical simulations also show that angular-dependent temperature changes due to the illumination condition change could be accurately estimated in combination with deriving spectral surface emissivity under

Lambertian assumption. But it is more difficult to solve a general case where angular-dependent temperature changes are coupled with bidirectional reflectance characteristics of the surface.

The following critical steps have been identified to ensure the quality of measurement data.

1) Determination of instrument response function and its stability.

2) Determination of the spectral emissivity of the blackbody surface.

3) Development of multiple calibration methods.

4) Accurate measurement of downward atmospheric radiation.

5) Bidirectional reflectance distribution function (BRDF) of diffusely reflecting plate.

6) BRDF measurements of target surfaces.

7) Accurate separation of the effects of reflectivity/emissivity and temperature change.

8) Evaluation of any assumptions used in measurements and data processing.

2.3. Development of Calibration and Validation Plans for LST Algorithms

2.3.1. Calibration sites for MODIS TIR bands

It is very important to find some good ground sites for absolute calibration of the MODIS thermal bands. Radiative transfer simulations show that the atmospheric transmission function for summer midlatitude atmosphere over a lake surface at elevation 4 km above sea level is larger than 0.95 for the most part of the atmospheric window 10 – 13 µm, and that the difference between the radiance at the top of the atmosphere and the upwelling radiance at the lake surface is less than 1% for the wavelength range from 10.4 to 12 pm. If a fair knowledge of atmospheric temperature and water vapor profiles is available, it seems not difficult to make an atmospheric correction to achieve the accuracy requirement of 0.5% for ground-based calibrations. The major uncertainty will be in measurements of the lake surface temperature. We need to make very accurate radiometric measurements. Or if we can find some alpine lakes which is partially frozen, then the temperature of the free water surface area is believed to be very close to 0°C without measurements. Several such lakes are found in the Tibet region, as shown in Table 1. Nam Co (Tengri Nor) is located at 30.40N, 90.30E with average length 80km and width 50km at elevation of 4718m above sea level, and a frozen period of November - May. It is located about 100km north-west of Lhasa. It will be an ideal TIR calibration site for meteorological satellites and EOS sensors if an international joint project can be organized with funding from participating countries so that a permanent station could be established. Even without a permanent station, it can be still used as a calibration site occasionally, once a year or every two years. More Tibet lakes will increase the chance suitable for calibrations without much ground supports. After discussing with the EOS/ASTER Science Team, I have proposed Tibet lakes as a ground calibration site for MODIS and ASTER.

TABLE 1. Tibet lakes to be used for ground calibration of MODIS and ASTER TIR data.

Name	Latitude	Longitude	Altitude meters	Lake Area sq. km.	Length & Width km-km	Depth m	Frozen Period
Nam Co (Tengri Nor)	30° 40’	90° 30’	4718	1940	79-50	39	Nov - May
Silling Co	31°50’	89° 00’	4530	1640	78-21	30	Nov - May
Dangra Yum Co	31°03’	86° 36’	4532	835	72-12	25	Nov - May
Zhari Num Co	30° 57’	85° 30’	4613	996	54-18	6.3	Dec - May
Mapam Yum Co	30° 40’	81° 23’	4588	412	26-16	49	Dec - May
La ‘nga Co	30° 45’	81° 15’	4573	268	29-9	15	Dec - May
Aksayqin Hu	35° 10’	79° 50’	4840	158	19-8		Nov - May
Gozha Co	35° 02’	81° 05’	5080	253	30-8		Oct - May
Yamzho Yum Co	29° 00’	90° 45’	4441	638	74-9	23	Nov - May

In order to use lake surface temperature to validate satellite data we need to know its seasonal change and spatial homogeneity. So a series of clear-sky image data over a long period of time are desirable. I used the Global Land Information System (GLIS) software package at EOS Data Center (EDC) of U.S. Geological Survey to look at the browse images in the EDC 1 km AVHRR archive to select clear-sky or low cloud-coverage scenes. After a long time searching, I found 26 low cloud-coverage scenes over Tibet lakes over the time period from April 91 to March 93, as shown in Table 2. A list of 10 scenes within these 26 scenes was sent to Dave Carneggie of USGS/EDC as my first data request from the EDC global 1 km AVHRR database.

2.3.2. Validation sites for LST algorithms

The MODIS Land group will select about 60 sites in the global to validate MODIS land products, and LTER sites will be considered as potential candidate sites. In addition to these sites, several lakes including the Great Lakes and Lake Tahoe will be also used as validation sites for LST algorithms. The EDC GLIS was also used to search clear-sky image data over these lake sites.

2.4. Other Activities

I attended the 16th Annual Review Conference on Atmospheric Transmission Models on June 8-9, 1993 at Hanscom Air Force Base, Bedford, and made a presentation titled “A urgent need of validating water vapor absorption coefficients for the development of EOS’s earth surface temperature algorithms”.

TABLE 2. A list of 1 km AVHRR scenes over Tibet lakes.

entity ID	date acquired	sat. No.	data type	pas dur	day night	receiving station	rnicroframe number
AL11031793092208	03/17/93	11	1KM	11	D	NOA	MH0009555
AL11012793091217	01/27/93	11	1KM	11	D	NGC	MH0006530
AH11121592093456	12/15/92	11	1KM	14	D	BJG	MH0007283
AH11110492092637	11/04/92	11	1KM	14	D	BJG	MH0006608
AH11100292092215	10/02/92	11	1KM	13	D	BJG	MH0006896
AH11090I92084719	09/01/92	11	1KM	19	D	BJG	MH0003889
AH11080592091516	08/05/92	11	1KM	13	D	BJG	MH0003779
AL11070492085107	07/04/92	11	1KM	11	D	NOA	MLB013451
AH11060192084536	06/01/92	11	1KM	18	D	BJG	MH0000959
AH11040292090358	04/02/92	11	1KM	14	D	BJG	MH0000482
AH11041392083153	04/13/92	11	1KM	15	D	BJG	MH0000503
AH11041292084401	04/12/92	11	1KM	12	D	BJG	MH0000502
AL11030292082433	03/02/92	11	1KM	11	D	NOA	MLB010780
AL11010992084723	01/09/92	11	1KM	11	D	NOA	MLB009718
AL11121791081513	12/17/91	11	1KM	11	D	NOA	MLB009208
AL11112291080609	11/22/91	11	1KM	11	D	NOA	MLB008694
AL11111991084140	11/19/91	11	1KM	11	D	NOA	MLB008620
AL11111391081052	11/13/91	11	1KM	11	D	NOA	MLB008495
AL11100891082821	10/08/91	11	1KM	10	D	NGC	MLB007747
AL11090491081921	09/04/91	11	1KM	10	D	NOA	MLB006992
ALI10E0191080854	08/01/91	11	1KM	10	D	NOA	MLB006364
AL11071491081440	07/14/91	11	1KM	10	D	NOA	MLB006005
AL11060991081358	06/09/91	11	1KM	10	D	NOA	MLB005345
AL11050491082308	05/04/91	11	1KM	10	D	NOA	MLB004698
AL11050491082308	05/04/91	11	1KM	10	D	NOA	MLB004698
AL11041891080414	04/18/91	11	1KM	10	D	NOA	MLB004409

3. Analysis

0n May4, I sent to the MODIS team leader some quantitative results on the necessity of nonlinear quantization for MODIS bands 31 and 32. Nonlinear quantization was required in the MODIS original specifications. In light of descope, it has been changed to linear quantization and the T_{max} was increased from 324°K to 400°K for both bands 31 and 32 in order to see small-size fires without saturation. The major effect of increasing T_{max} to 400°K is that the radiometric dynamic range of bands 31 and 32 would be increased by 120% so that the quantization noise equivalent differential temperature (NEdT') will be larger than optical noise equivalent differential temperature (NEdT) even at a typical temperature, 300 'K. And MODIS system signal-to-noise ratio will be limited by quantization in the whole temperature range. At 300°K, NEdT' will be 0.051°K so that an error of about 0.3°K in the split-window SST algorithm will come from just the quantization error. At a low temperature, 233 'K, NEdT' will be 0.11°K so that the quantization alone would contribute an error of about 1 K into the surface temperature estimated from split-window methods. Based on this analysis, I made the following recommendations:

3.1. Nonlinear quantization is needed if T_{max} is set at 400°K.

1) In order to characterize system noise equivalent differential temperature (NEdT) and radiance (NEdL) pre-launch, NEdT's must be much less than NEdT. Otherwise, quantization will limit MODIS thermal bands 31 and 32 and it will be impossible to get system noise characteristics for potential improvement of data quality in the long run.

2) Radiative transfer simulations show that at a zenith angle of 540 the brightness temperature of AVHRR band 5 changes only 0.035°K as sea surface temperature changes by 0.20°K. Noted that the maximum viewing angle of MODIS at the earth surface could be up to 650 from nadir. There will be no enough radiometric resolution to detect a SST change of 0.2°K if T_{max} =400°K and linear quantization is applied.

3) A high radiometric resolution is also required in the low temperature range for estimating snow/ice surface temperatures.

4) A specification for nonlinear quantization: NEdT' $\leq$ 0.026°K at 300°K.

3.2. An alternative solution

An alternative solution for bands 31 and 32 is to set T_{max} at 335°K if nonlinear quantization is too costly.

3.3. A simple modification in favor of fire detection

The T_{max} for band 33 is increased to 335K from 285K.

4. Anticipated Future Actions

1) to complete the LST Algorithms Theoretical Basic Document by July 30, 1993;

2) to make detailed characterization of the thermal infrared measurement system including spectrometer, blackbody and radiation sources;

3) to make emissivity and temperature measurements of water surface and grass field with the MIDAC M2401 spectrometer

4) to make conceptual and engineering design of an accessory system for spectrometric measurements at variable angles.

Appendix 1. Comparison between several spectroradiometer.

company	MIDAC	BOMEM	Optronic Lab.	Cl Systems
model	M2401	BM155	750D	SR-5000
spectral range (µm)	2.5-16	0.7-22	0.2-30	0.4-14
optic design	interferometer	interferometer	grating	CVF
resolution	.5-32 cm-’	1-128 cm-1	300nm?	1.35-2.2% λ
FOV	20 mrad	5-350 mr		l-6mr & 5.7deg
wavelength accuracy	.01 cm-’	.01 cm-l	0.05%	1%
ADC bits		16		14
scan speed	1-/sec	40-90/min		0.015-2/sec
fast scan option				yes 10/sec
max scan length	1 cm	1 cm	NA	NA
reference laser	He-Ne	He-Ne	NA	NA
beamsplitter	ZnSe	KCl	NA	NA
compensator	ZnSe	beamsplitter self	NA	NA
max no. detectors	1	2	4	1
NEI			$1X10^{-8}$?	$8x10^{-12}$ Wcm^{-2}
NEdT				.05 K at 100C
rad. accuracy		0.2%		
stability		0.25%		
weight	17 or 27 lbs	=70 lbs	62 lbs	55 lbs
size	8“x7”x12"	20”x15“x22"	17“x10“x28”	14“x7.5’’x27”
operating temperature (“C)		-15 to 50	5-40	
voltage (V)	11 0/220	11 0/220	11 0/220	11 0/220
battery option	yes 12V	yes 12V	yes 12V	
power requirement	50W	150W		
computer	PC/Notebook	PC/Notebook	PC/?	PC/?
basic system price	$40K (2.5-16 µm)	= $52K (2-14Km)	$57K (1-14µm)	$68K (1-14µm)
company address	MIDAC Corp. 17911 Fitch Ave. Irvine CA 92714	450 Av. St-Jean-Baptiste Quebec CANADA	4470 35th St. Orlando FL 32811	5137 Clareton Dr suite 220 Agoura Hills CA 91301 (moved from NY)
companies make similar products	Designs & Prototypes	Nicolet	ARC J-Y/SPEX OREIL	Infrared Systems Sira Ltd. UK